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STATUS AND DEVELOPMENT TRENDS IN MISSILE WARHEADS
(CONVENTIONAL POWDER CHARGE) (LAST PART OF ARTICLE)

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IV. Warheads for Ground Targets

1. Analysis of Targets

There are numerous types of ground targets; based on defense capability, targets may be classified as hardened, soft, or semihardened. Based on the target shape and area of dispersion, there are point targets, linear targets, and planar targets. In the category of hardened targets, there is an underground silo and reinforced concrete bunkers, among other structures. Of the soft targets, there are conventional military targets. Of the semihardened targets there are airfield runways and aircraft hangars. In the category of point targets, there are radar sites, command centers, and military ammunition dumps, among others. Among linear targets, there are airfield runways and railroad trestles, among others. In the planar target category, there are cities, ports, communication link centers, missile launch bases, and airfields, among others.

Features of ground targets: most targets are stationary structures with relatively large area, of many structural types, and with different degrees of sturdiness.

With respect to the missile warhead, currently the major requirements when striking ground targets include the following:

(1) Airfield runways and aircraft hangars
(2) Railway junctions and ports
(3) Missile launch sites and radar sites
(4) Moving cluster type targets

2. Status of Warhead When Striking Ground Targets

Weapons of various types can be used to strike ground targets, such as ground-to-ground missiles and air-to-ground missiles with respect to guided missile use. Generally, the range of ground-to-ground tactical missiles with conventional explosives is between 100 and 350 kilometers. The range of air-to-ground missiles with conventional explosives as warhead is between 3 to 100 kilometers.

Generally recognized internationally, the magnitude of the K value as the casualty and explosive capability is the criterion for using weapons or writing them off as obsolete:

$$K = \frac{K_1 M_w^{2/3}}{r_c} \qquad (kg^{2/3}/km^2) \qquad (6)$$

In the equation: K -- casualty and explosion capability of ordnance ($kg^{2/3}/km^2$)

M_W -- mass of warhead

r_C -- circular error probable

K_1 -- rational coefficient for deciding structural design of warhead

From statistics, the required K_n for casualty and detonation during the destruction and damaging of various types of ground targets are as follows:

for ground targets of smaller areas, $K_n=3.3\cdot10^3\ kg^{2/3}/km^2$

for larger and densely placed ground targets,

$$K_n=2\cdot10^2\ kg^{2/3}/km^2$$

for tank targets, $K_n=10^6\ kg^{2/3}/km^2$

Before the seventies, since the circular error probable r_c of missile guidance systems was relatively high, most warheads of ground-to-ground missiles were of the integrated type (that is, the value of K_1 is relatively small), the mass M_W of the warhead could not be arbitrarily increased because of limited total missile weight. Therefore, at that time it was considered that the conventional powder charge of the warhead in a ground-to-ground missile had no future prospects. In ground-to-ground missiles, there are only the following types with the warhead attachment (refer to Table 3).

Since the seventies, the guidance precision of missiles has been greatly improved. The warheads of various types of dispensers and bomblets were successfully developed. These advancements opened wide prospects for deploying conventional warheads of ground-to-ground missiles.

To strike hardened targets on the ground, the warhead should make a direct hit in addition to higher penetration detonation capability. To strike ground-based soft targets, generally the warheads adopted cluster type compartments, casualty causing detonation compartments, or fog warhead.

The air-to-ground missile is used mainly to attack ground bridges, airfields, power stations, fuel depots, and radar sites. These missiles are fitted with blast/fragmentation warheads, fragmentation warheads, and blast warheads. Table 4 lists the data of warheads of air-to-ground missiles of highly superb air-to-ground missiles.

TABLE 3

国别 1	型号 2	口径（毫米） 3	最大射程 X_m（公里） 4	战斗部质量 M_w（千克） 5	圆公算偏差 r_c（米） 6	杀爆能力 K（千克[illegible] 公里[illegible]） 7
美 8	“长矛” 11	560	120	454	150	4.72 × 10[illegible]
苏 9	12 “飞毛腿”A	880	110	680	370	2.50 × 10[illegible]
苏 9	“飞毛腿” 13 B	880	300	1000	300	3.66 × 10[illegible]
苏 9	“薄板” 10	1000	800	680	500*	2.01 × 10[illegible]

KEY: 1 - Country 2 - Model 3 - Diameter (mm) 4 - Maximum range, X_m (km) 5 - Warhead mass M_W (kg) 6 - Circular error probable, r_C 7 - Casualty and detonation capability K ($kg^{2/3}/km^2$) 8 - United States 9 - Soviet Union 10 - Thin plate 11 - Lance 12 - Scud A 13 - Scud B

The following structures of typical warheads:

(1) Prefabricated fragmentation type warheads (refer to Fig. 11) are fitted into anti-radiation missiles, which are used to attack radar sites. By relying on fragments, the missile destroys radar equipment and causes casualties among the operators.

(2) Plate-shaped, self-forging fragmentation warhead (refer to Fig. 12): eight V-shaped slots form plate-shaped self-forging fragments after detonation of the main powder charge. These warheads are used to destroy sturdy targets, such as bridges and airfields.

TABLE 4

国别 1	导弹型号 2	战斗部类型 3	战斗部直径（毫米） 4	射程（公里） 5	战斗部质量（千克） 6	引信 7
法 8	AS-30L	16 半穿甲式	342	12（最大） 18	245	延时引信 24
		17 爆破式		3（最小） 19		触发引信 24
8 法	11 阿玛特	爆破破片式 18	396	93	150	近炸引信 22
法 8	玛特尔 12	17 爆破式（AJ168）	400	60	150	触发引信 21
		17 爆破式（AS-37）				近炸引信 22
9 美	白星眼 13	20 片状自锻破片式	390	9	66.7	23 无线电比相引信
9 美	14 秃鹰	片状自锻破片式 20	430	60～80	286	
美 9	幼畜 15	17 爆破式	305	48	58.7	21 触发引信
		16 半穿甲式			135	22 延时引信
10 苏	AS-7	17 爆破式	310	10	100	19 近炸引信与触发引信

KEY: 1 - Country 2 - Missile model 3 - Types of warheads 4 - Diameter of warhead (mm) 5 - Range (km) 6 - Mass of warhead (kg) 7 - Fuze 8 - France 9 - United States 10 - Soviet Union 11 - Amanda 12 - Martel 13 - Eye of white star 14 - Bald eagle 15 - Bullpup 16 - Semi-armor-penetrating type 17 - Detonation type 18 - Fragmentation type 19 - Proximity detonation fuze and triggering fuze 20 - Plate-shaped self-forging fragmentation type 21 - Triggering fuze 22 - Proximity detonation fuze 23 - Radio phase comparison fuze 24 - Time-delay fuze

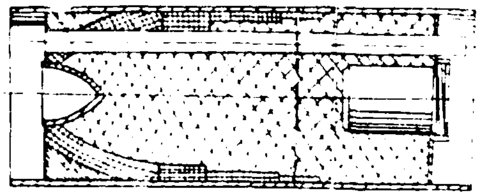


Fig. 11. Prefabricated fragments warhead of anti-radiation missile

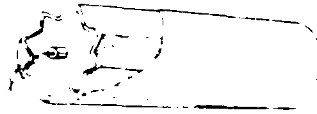


Fig. 12. Plate-shaped self-forging fragmentation type warhead

3. Development trend of warheads striking ground targets

Since the artillery range is within 30 to 40km, although the range of uncontrolled rockets can reach 50 to 70km, yet their precision is low. Generally, the range of strategic missiles is more than 800km. Therefore, this is a void for targets in the region between 40 and 800km (especially between 40 and 300km). In recent years, inside and outside of China emphasis has been placed on studying how to strike ground targets in this region. In the situation of improving the guidance precision and of reducing the scattering state for tactical missiles, the warheads of conventional powder packs have broad developmental prospects. In addition, with some progress in the U.S.-Soviet negotiations over banning and destroying nuclear weapons, the view of fitting conventional warheads in strategic missiles has been gradually adopted. Generally, the developmental trend is as follows:

(1) Warheads with dispenser and bomblets were stressed. Striking clusters and high density area targets, a warhead with dispenser and bomblets is the most economical and most efficient means. By features, warheads with dispenser and bomblets are divided into active radar homing, semi-active radar homing, and

unguided types. With advances in science and technology, the unguided type (without terminal guidance) warhead with dispenser and bomblets will be gradually displaced by the semi-active radar homing (with terminal guidance) and radar homing types (self-homing) warheads.

For unguided warheads, extensive research is necessary on the casting of the missile, coverage and firepower of bomblets, and overall missile efficiency.

For semi-active radar homing and active radar homing types of warheads with bomblets, the selection should be optimized according to predetermined targets based on the kind of destruction and the quality of bomblet warheads.

(2) For the deployment of different types of warheads in the same missile model, warheads must be selected with kinds of destruction mode because of numerous ground targets and for effective destruction of different targets (hardened and soft targets). Generally, there are fragmentation, casualty producing type, penetration detonation type, concentrated-energy armor-piercing type, and shock wave superhigh-pressure type. Prefabricated warheads closer to standardization and modularization will adequately exploit the function of missiles in warfare.

(3) Dev loping warheads with terminal guidance and proximity-sensitivity will result in transferring effective separation guidance technique of ground-to-ground strategic missiles into the conventional powder pack warheads.

(4) A trial was pursued to adopt fuel-air dynamite. Owing to area detonation and the generation of high intensity shock waves, the fuel-air dynamite has a wide range of explosive impact so as to destroy ground vehicles, to cause casualties, and to

destroy ground structures; these are all very effective. In compounding preparation research and development of fuel-air dynamite in China, Al powder is added to propane tetrachloride to have a significant effect; the power level has been achieved such that 1kg of hydrocarbon is equivalent to 5kg of TNT.

(5) Enhance the destructive force to the optimal research on semihardened targets. Concretely speaking, these semihardened targets are airfield runways and aircraft hangars. Since an airfield is a linear target with its area of (2000 to 3000)m x (40 to 60)m, and generally with concrete thickness of 20 to 40mm and a thick soil layer covers the aircraft hangars. In the current situation in China in whi h air superiority remains to be achieved, an airfield runway that can withstand enemy attacks is an important challenge. The ground-to-ground or air-to-ground missile is a vital weapon to neutralize an airfield. The design of a warhead for effectively neutralizing an airfield and for prolonging its function for an extended time remains as a challenge.

V. Warheads Striking Maritime Targets

1. Analysis of Maritime Targets

Maritime targets include surface vessels and submarines. Surface vessels include aircraft carriers, cruisers, guided-missile destroyers, and frigates. After World War Two, light vessels became capital ships.

The features of maritime targets are as follows: survivability of a warship is high with certain protective armor-plating, high-firepower, and small size.

With respect to warheads, currently the main striking targets are as follows:

(1) Nuclear submarines

(2) Intermediate size vessels, mainly guided-missile destroyers and frigates

(3) Cruisers

2. Status of Warheads Striking Maritime Targets

Antiship missiles have become the major weapons for striking surface vessels; these missiles can be launched on different occasions (in the air, along the coast, from another vessel, and from underwater). The same missile can also be used on different occasions. From incomplete statistics, there are 95 types of antiship missiles fitted with conventional explosive warheads. The chosen warheads are mainly of four types: semi-armor-piercing warheads, detonation warheads, concentrated-energy armor-piercing warheads, and semi-armor-piercing self-forging fragmentation warheads. Table 5 lists data of typical antiship warheads.

Typical warheads have the following structures:

(1) Semi-armor-piercing detonation type warheads (Fig. 13): The typical structure is seen in the French Exocet antiship missile. When the angle of incidence is 70°, the missile will not bounce off. Generally, an Exocet missile can neutralize the weaponry of an intermediate-size warship. When the missile strikes the target directly (80% probability), the time delay fuze becomes activated; for smaller vessels, the proximity detonation fuze of the missile becomes activated when the missile flies over the vessel.

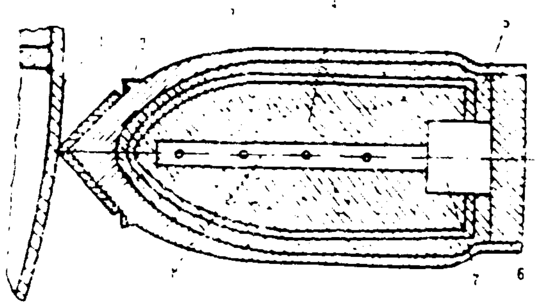
(2) See Fig. 14 for semi-armor-piercing, self-forging fragmentation type warheads. The typical structure is the

warhead of the Kormoran missile from West Germany. When the missile hits a vessel with an angle of incidence of 60°, the missile can penetrate 12mm of steel plating to enter the ship for 3 to 4m (relying on 14ms of fuze time delay). The warhead detonates and the self-forging fragments are distributed along the circle with 16 wedge-shaped slots to penetrate the vessel compartment at an initial velocity of 3000m/s.

TABLE 5

国别 1	导弹型式 2	战斗部型式 3	直径（毫米） 4	战斗部质量（千克） 5	引信类型 6	备注 7
法 8	飞鱼 13	半穿甲爆破型 19	350	165	22 延期引信 近炸引信 23	
意、法 9	奥托马特 14	半穿甲爆破型 19	460	210	延期引信 22	25 能穿透40毫米甲板
美 10	捕鲸叉 15	半穿甲爆破型 19	344	230	22 延期引信 近炸引信 23	
1 苏	16 冥河	20 聚能爆破型	760	500	24 触发引信	
西德 11	鸬鹚 Ⅰ 17	21 半穿甲自锻破片型	344	160	延期引信 23	26 可穿透七层舱壁
西德 12	鸬鹚 Ⅱ 18	半穿甲 21 自锻破片型	300	220	延期引信 23	

KEY: 1 - Country 2 - Missile types 3 - Warhead type 4 - Diameter (mm) 5 - Mass of warheads (kg) 6 - Fuze types 7 - Remarks 8 - France 9 - Italy and France 10 - United States 11 - Soviet Union 12 - West Germany 13 - Exocet 14 - Automat 15 - Harpoon 16 - Styx 17 - Kormoran I 18 - Kormoran II 19 - Semi-armor-piercing blast type 20 - Energy-concentrating blast type 21 - Semi-armor-piercing, self-forging fragmentation type 22 - Time delay fuze 23 - Proximity detonation fuze 24 - Contact fuze 25 - Capable of penetrating a 40-mm thick deck 26 - Capable of penetrating seven compartment walls



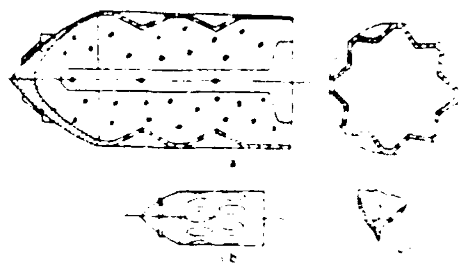


Fig. 13. Semi-armor-piercing blast warhead
Remarks: 1 - Deck of target
2 - Bouncing-proof claw
3 - Shell 4 - Dynamite
5 - Chassis 6 - Safety mechanism and primer 7 - Detonation transfer pipe
8. Detonation triggering device

Fig. 14. Semi-armor-piercing self-forging fragmentation warhead
Remarks: a - Structural block
b - Exterior diagram
c - Launched missile

(3) Refer to Fig. 15 for energy concentrating armor-piercing detonation type warhead. The typical structure is seen in the Styx warhead of the Soviet Union; the warhead is used mainly to strike large surface vessels with thick armor. After detonation of the warhead, a relatively large diameter metal stream opens a very large hole in the vessel. Based on the engineering calculation formula, the following parameters can be estimated:

Diameter of the hole thus opened $D=0.7d$ (mm)
Depth of armor penetration $L=2.5d$ (mm)

In the equation, d is the internal diameter (mm) of the missile casing.

The shock wave acts to expand the dimensions of the hole thus opened in the vessel, and seawater rushes into the vessel, resulting in its sinking.

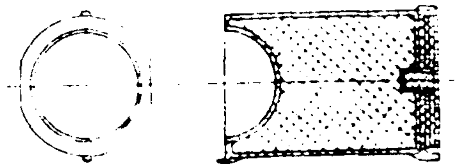


Fig. 15. Energy-concentrating armor-piercing blast warhead

Currently, there is a total of ten models developed throughout the world for antisubmarine missiles. Three out of ten models have nuclear warheads; the other models launch torpedoes. The torpedo models are MK-46 and Fu [transliterated] fish; the MK-46 was made in the United States at an earlier period; its warhead is a detonation warhead. Fu fish is a product successfully developed recently in Britain; its warhead is of the energy-concentrating type capable of effectively striking various types of submarines.

3. Development trend of antiship missile warheads

After World War Two, development of antiship missiles was very rapid. Especially during the Falklands war in 1982 and the American Libyan conflict in 1986, antiship missiles showed their firepower, meriting attention from countries around the world. There are more than 70 countries equipped with different models of antiship missiles, which have been developed to the fourth generation.

As for antiship missile warheads, the current development trend is as follows:

(1) Development of semi-armor-piercing self-forging fragmentation warheads of supersonic (M=2) antiship missiles: with the rapid strides in antimissile missile technology, subsonic antiship missiles are confronted with defense

penetration difficulties. The fourth-generation antiship missiles adopt supersonic flight (M=2 to 4), in additional to stealth invisibility technology. To satisfy the requirements of M=2 and the missile warhead penetrating an enemy vessel, the following technical problems should be solved when the impact load is 50,000 to 60,000g, shell strength, dynamite stability and strength, as well as fuze reliability and explosion transferring series. In addition, it is schemed to obtain the complete self-forging fragment in the powder pack design.

(2) The energy-concentrating effect technique is applied to antisubmarine missile warheads (torpedoes). On the strengthening of the defensive capability of nuclear submarines, if a titanium alloy (nonmagnetic) is used as the hull, this will render ineffective present-day torpedoes using magnetic or electromagnetic fuzes. By adopting composite materials such as acoustic absorption coating or fitting with a rubber layer, this will drastically reduce the self-guidance distance of a torpedo. In its structure, the distance between the protective layer and the pressure-proof hull is increased to 2m, which renders the conventional small torpedoes ineffective if they use a detonation warhead. By applying the energy-concentrating effect technique of torpedoes in anti-submarine missiles, an enemy submarine can be destroyed by opening a hole larger than 20mm on the pressure-proof hull of the submarine by metal stream flow following the detonation when the powder charge is as low as 40kg.

(3) Development of fuel-air dynamic warhead: Since fuel-air dynamite has a large destruction range, currently a dynamite pack of 1kg of hydrocarbons corresponds in detonation effect to that of 3 to 4kg TNT dynamite. As revealed by tests, 500kg of epoxy methane charge can seriously damage or destroy all vessels with 50m from the fringe of the gasified fog, or cause intermediate-degree damage to all vessels within 85m from the fringe of the gasified fog. For the second-generation development level, the

United States is planning to raise the fuel-air dynamite energy to the equivalence of 10 times TNT. If this technology is successfully developed, all vessels within 150m from the fringe of the gasified fog will be sunk or seriously damaged, or intermediate-degree damage to all vessels within 210 to 240m from the fringe of the gasified fog.

Conclusions

From the foregoing analysis, progress was made with the conventional powder pack warhead, with the advances in technology in the struggle against various types of targets. The author enumerates his views regarding the status and development of China's warhead system, as follows:

1. Like the other missile subsystems, the technical level of China's missile warheads was developed extensively over the three decades following 1958 to generally cope with the development and production requirements of missile undertakings. However, we should understand that there is still a gap between the Chinese technology and the technical level of the advanced nations, mainly manifested in the design and technical levels. The gap in the design levels is due mainly to the fact of backward design concepts and the lack of new creative concepts and new ideas for developing new products; the design method is still trial-and-error in its approach and testing without establishing relatively complete design criteria and the lack of standardization of work. The gap in the technical level is exhibited very clearly in the backward technique of the powder charge, inadequate quality of precision machining equipment, as well as poor test facilities.

2. To further advance China's warhead technical level, the following tasks should be performed with care:

(1) Stress the application of basic research and preliminary

study of applied research. As to demands that appear at present and will appear in the future wars, pick up targets that should be seriously coped with, such as low-altitude invading aircraft, reactive armor tanks, tank clusters, nuclear submarines, and spacecraft (among others), for developing effective destroying mechanisms and mastering the related rules in order to provide the theoretical basis for warhead development.

(2) The development of the warhead subsystem should be considered as a problem in systems engineering. Thus, the fuze, detonation transferring series, powder charge, and the warhead are organized into an organic entity, to study, from the mechanical point of view, the force transfer between the powder charge (energy source), transmission medium, and the target in order to study the conversion transmission among the three from the energy viewpoint, in order to find a scheme for the optimal matching between fuze and warhead, as well as the optimal design of the powder charge structure.

(3) Adopt the advanced design method (such as optimization) and to extensively apply the advanced experimental and computer technology in order to establish the steady approach of three-in-one in engineering estimation, simulation and numerical computation, as well as experimentation. The detonation process of the warhead is a high-pressure, high-temperature, and high-speed deformation moving process; the phenomena of the detonation process should be completely recorded by high-speed photography and pulse x-ray photography. Rapid development of modern electronic computer technology, as well as applied numerical calculation and simulation can be used to arrive at a detailed description of the process between detonation and the trajectory process to the terminal point, as well to forecast some important regularities and phenomena. As for problems relating to the terminal point effect of warheads, such as armor destruction, armor piercing, casualty producing, high speed collision, as well

as in air, earth, and underground detonations by using numerical methods to achieve outstanding qualities and to develop numerous software programs with practical value.

For the predetermined striking targets, a warhead should have an ideal destructive effect. The destructive effect is inseparable from the timely and sensitive detection of a target by the fuze and satisfactory properties of detonating completely and reliably. With good matching of performance parameters between the fuze and the warhead, the weapon can achieve optimal efficiency.

With respect to conducting warhead research, for better matching between the fuze and the warhead, the corresponding requirements are also necessary in fuze development.

(1) As to fuze types, for fuzes coping with air targets, developmental work should be conducted on variable frequency fuzes, modulating frequency fuzes, and laser fuzes, for achievements in antijamming, reliability, fuze matching performance and miniaturization. For fuzes striking armored targets, there should be developmental work on proximity detonation fuzes and intelligent fuzes, to ensure detonation effect after timely discovery of a target for striking. For fuzes used against ground targets, there should be research on time delay fuzes and intelligent fuzes ensuring a penetration depth for semihardened targets during high-speed impact for noncontact fuze of dispenser and bomblet warheads with noncontact fuzes operating at a definite altitude. For fuzes striking maritime targets, there should be work done on intelligent fuzes capable of looking for critical sites of an underwater submarine, as well as time delay fuzes that ensures reliability in high supersonic penetration of the side plating of a vessel.

(2) As for coordination between fuze and warhead, the most critical problem is to select or ensure the position of the optimal detonation under the given firing conditions or matching conditions. In reality, there is always the fuze coordination in coping with various types of targets. Current research is limited only to air targets since the research is not yet systematic, therefore up to now no mathematical model with high universality can be established. Computer simulation should be applied to coordinate the fuze and warhead personnel to perfect and establish the mathematical models and computation method coping with various types of targets for coordination between fuze and warhead. In addition, gradual standardization is proceeding to provide an integral method for computation of weapon efficiency.